ADVANCES IN WATER WORKS EQUIPMENT AND PRACTICE IN THE PAST FIFTEEN YEARS[1]

SAMUEL SHENKER
Chemist, Water Purification Plant,
Columbus, Ohio

"Water," says the humorist, "is something that they put under bridges." We take it for granted and only when the well goes dry do we do anything about it if we do anything then. Only a few per cent of any community know anything about their water works system and I suppose that we, i. e., water works men, are largely to blame ourselves. Within the past five years or so, the American Water Works Association has started a program to stimulate interest in water works personnel to inform the public about the function of their department. The slogan is "Silent Service is not Enough."

The importance of water was brought into focus within the past six months, or so, when a low of 37% of the capacity of the reservoirs of New York City was reached. I suppose that you read of many incidents that occurred in New York because of this shortage. Here in Columbus in February of 1945 we only had about three feet of water in each reservoir and only one day of thawing weather, when the temperature reached 70° F., saved us from going completely dry because of the severe weather. To date our supply has not been increased substantially. In Loudonville, Ohio, only a few years ago, you may remember that about half the population of 2500 contracted gastro-enteritis because of a slipup in operation and probably planning.

The beginning of modern water purification goes back to 1829 when James Simpson constructed a slow sand filter in London, England. Previous to that time even as long ago as the beginning of the modern era, alum had been used to clarify turbid waters and methods of clarification by repeated settling and decantation had been used. Then, about the middle of the 19th century Koch's spectacular work on micro-organisms stimulated thinking along the line of removal of pathogenic organisms.

The first filters to be built in this country were installed in Poughkeepsie, N. Y., in 1870, and the first filter plant to use alum was constructed at Somerville, N. J., in 1884. In that year Alpheus Hyatt secured a patent for the process of the use of alum as a coagulant. One of the stalwarts in the design and construction of water works plants, Mr. George W. Fuller and an associate Charles Hermany introduced rapid sand filters in 1895 to 1897 which has served as the basis for the design of mechanical filters constructed in this country. The Columbus plant, which went into operation in September, 1908, was the first combined softening and filtration plant. George A. Johnson did some preliminary analyses and experimental work to determine the physical and chemical characteristics of the Scioto River water over a period of time which aided John H. Gregory, the designing engineer for the George W. Fuller Company in determining the layout of the plant.

The Columbus plant remained the largest combined softening and filtration plant until 1939 when a 100 MGD plant went into operation at Glendale, California, designed by the consulting firm of Hoover and Montgomery. This is a lime-zeolite softening plant and the water is obtained from Boulder Dam 350 miles away, and the waste water is run into a sewer of the city of Los Angeles and is conducted a number of miles to the ocean. This plant was superseded in size by that of Minneapolis in 1940 with a capacity of 120 MGD. Then the Chicago

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South District Filtration Plant went into operation in 1947 with a rated capacity of 300 MGD at a filtration rate of 2 gpm/square foot with an anticipated maximum capacity of 600 MGD at double the filtration rate. The plant has already treated 550 MGD. At this point it is interesting to note that both Chicago and New York use over a billion gallons of water a day, or about as much water as is stored in our own Griggs Dam when it is filled.

The primary reason for treating water is to improve its sanitary quality. In the period 1901–1908, before the Columbus plant went into operation, the average typhoid fever death rate in Columbus was about 55 per 100,000 population per

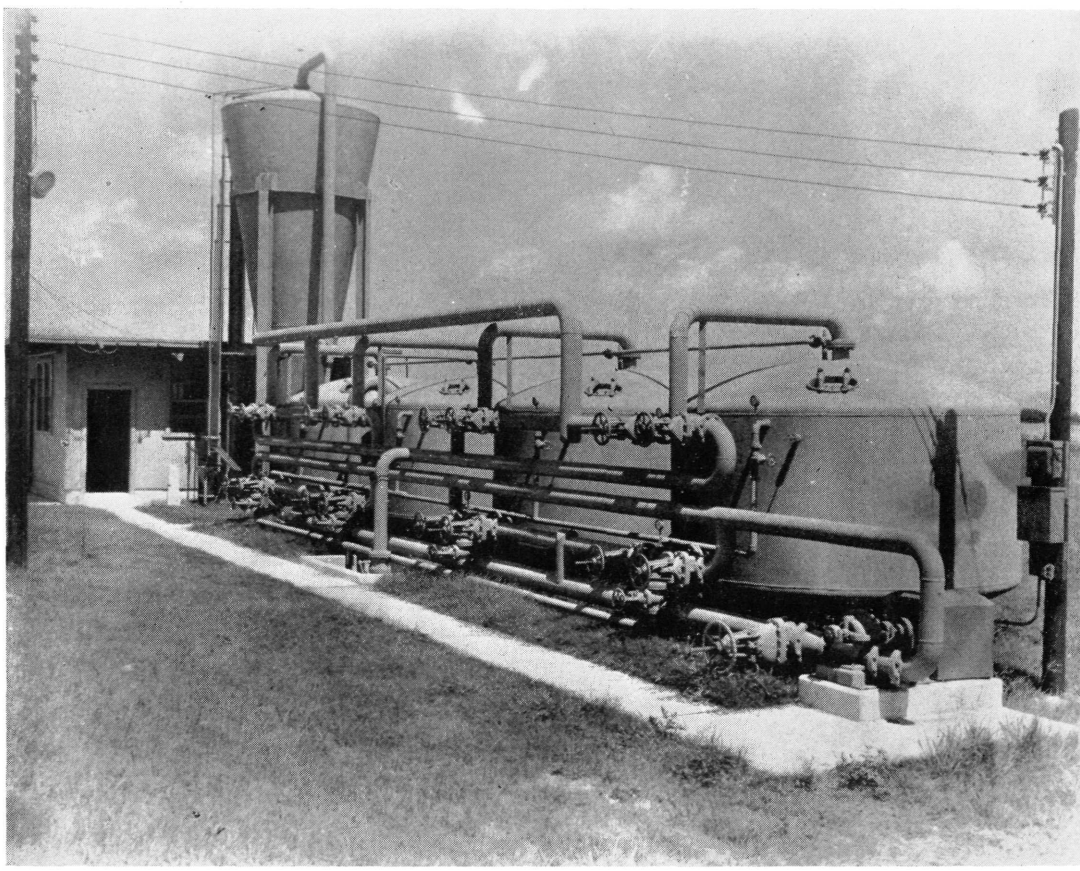

FIG. 1. This is a photograph of a spiractor installation showing a spiractor water treatment tank followed by filters which remove any turbidity carryover from the tank. These units eliminate the sludge problem. (By courtesy of the Permutit Company, New York City.)

year. Since 1917 we have had very few deaths here due to typhoid fever. That is true wherever treatment plants have been installed in the country. Water is also softened so as to reduce soap consumption in the home and elsewhere such as laundries and aids in reducing scale in the lines and in boiler tubes. Proper treatment is also an aid in the prevention of corrosion.

There are various types of water supplies, viz.:

1. Surface Waters.
   a. Those that traverse limestone beds, such as here in Columbus. These waters pick up calcium and magnesium from the limestone which causes the hardness in the water.

b. Those that traverse beds, such as the New York City supply. These waters are naturally soft since they do not pick up any calcium or magnesium.

c. Lake waters, such as the supplies in Cleveland and Chicago. These waters are moderately hard, 7 to 9 grains per gallon, and until recently have not been softened.

2. Ground Waters—All of these are hard waters.

a. Isolated aquifers, such as the supply of Lancaster, Ohio.

b. Systems of somewhat connected aquifers, known as underground streams, such as the Newark River from which the Mead Paper Co. of Chillicothe, Ohio, pumps about 20,000,000 gallons per day.

c. Infiltration from streams to gravel deposits adjacent to the stream, such as the former Columbus water supply along the Olentangy River opposite the present Municipal Light Plant where the city had six, six-inch wells.

d. Artesian wells as represented by the present Columbus water supply at the Alum Creek Plant. These waters are very hard.

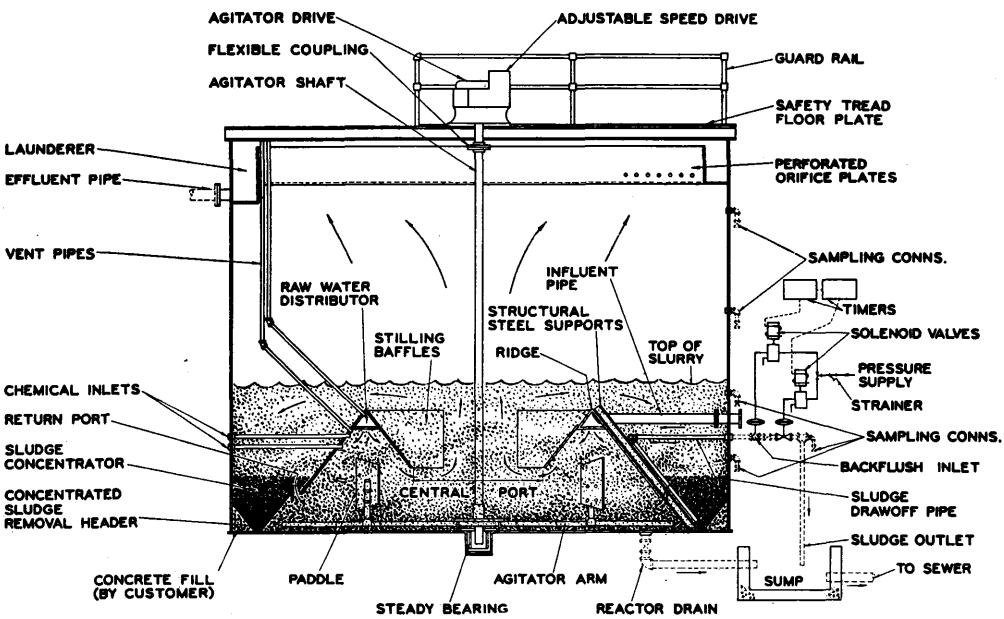

FIG. 2. This is a cross-section of the Cochrane Corporation's "Liquon" sludge contact reactor. This unit secures coagulation, clarification, sludge removal, and utilization of the sludge all in one tank. (By courtesy of the Cochrane Corporation of Philadelphia, Pa.)

The original Columbus plant consisted of square mixing tanks with vertical agitators revolving at low speed, a baffling tank where the water travels up and down vertically, settling basins which remove the sludge, rapid sand filters and a clear well. The next step in the design of water works equipment was the development of the clarifier by engineers of the Dorr Company in about 1920. Clarification and sludge removal was obtained in a single unit. Then in 1935 Charles Spaulding, of Springfield, Illinois, introduced the tank which bears his name and the Permutit Company bought his patents. This plant carries out mixing, coagulation, clarification, and utilization of the sludge to bring the water into chemical balance.

The Minneapolis plant is constructed with units of this type. The International Filter Company of Chicago also developed a unit of this type as did also Samuel Applebaum. The former is called an Accelator while the latter is called a sludge contact reactor. The village of Pataskala, Ohio, has an Accelator water treatment unit while there are sludge contact reactors at the Walnut Station and Poston Station of the Columbus & Southern Ohio Electric Company.

About 7 or 8 years ago a Czech engineer developed a new principle in water treatment known as catalytic precipitation. The patents were purchased by the Permutit Company. This unit consists of a conical covered tank with point downward and the inuflent and chemical feed lines just above the point of the cone. The aggregate is a granular catalyst screened to the proper grain size. The advantages claimed are:

1. The reaction goes to completion in 5 minutes.
2. Considerable saving in space and cost of installation.
3. No sludge waste to handle, only a little enlarged catalyst, to draw off occasionally, which can be broken up and reused, or disposed of readily.
4. No agitation required.
5. Units are relatively portable.

These units are called spiractors.

The tremendous, new Chicago filtration plant was carefully designed by some of the leaders in the water works field. One of the problems that Mr. Baylis solved in the laboratory before the plant went into operation, or even before it was at the blue print stage, was that of eliminating the deleterious effect of algae on the filters. Algae forms a slime on the filters which reduces the length of filter runs and is difficult to wash out. Mr. Baylis developed an aid to coagulation, viz silica sol, which hardened the floc and gave rapid filtration. Another problem that was solved to a great extent in this plant was that of air-binding of filters. This was accomplished by increasing the depth of water on the filter to about 7 feet whereas previously filters carried three to four feet of water over the sand. Two laboratory innovations in the Chicago plant are:

1. A centrifugal machine to concentrate organisms in the filtered water, and
2. An electronmicroscope.

LIME-SODA TREATMENT PLANT SOFTENING REACTIONS

1. $Al_2(SO_4)_3+3Ca(HCO_3)_2=2Al(OH)_3+3CaSO_4+6CO_2+3H_2O$
2. $Ca(HCO_3)_2+Ca(OH)_2=2CaCO_3$
3. a. $Mg(HCO_3)_2+Ca(OH)_2=MgCO_3+CaCO_3+2H_2O$
   b. $MgCO_3+Ca(OH)_2=Mg(OH)_2+CaCO_3$
4. $CaX+Na_2CO_3=CaCO_3+2NaX$
   Where X = anion, such as chloride, sulfate and nitrate.

Alum is the coagulant and removes the turbidity and most of the bacteria by the mechanical action of the aluminum hydroxide.

Lime reduces the carbonate hardness, calcium and magnesium bicarbonates, acts as an antiseptic in excess and also aids in the removal of magnesium when used in excess treatment.

Soda reduces the non-carbonate hardness, i. e., the chlorides, sulfates, and nitrates of calcium and magnesium.

The chemicals underscored are insoluble and form part of the sludge which is wasted. For every pound of quicklime used three and one-half pounds of calcium carbonate are formed.

ION EXCHANGERS

As far as is known, Robert Gans in 1906 was the first man to suggest the use of ion exchange materials for water softening. Both processed natural minerals,

so-called greensands, which are found in New Jersey and Nebraska, mainly the mineral glauconite, and synthetic materials have been developed with varying suitability for ion exchange uses.

Possibly the most significant development in water works materials in the past 15 years was that of the new class of synthetic resins, disclosed in 1935 by Adams and Holmes. The cation exchange resins are mainly sulfonated condensation products. Anion exchange resins are condensation products containing amino groups.

Ion exchange materials fall into three general groups:

1. Inorganic cation exchangers
2. Organic cation exchangers, and
3. Organic anion exchangers.

In the softening reactions, the inorganic exchanger is designated by Z and the organic exchanger by R. The reactions of the calcium salts with the ion exchangers are considered typical.

$$Ca(HCO_3)_2 + NaZ = CaZ + 2NaHCO_3$$
$$CaCl_2 + NaZ = CaZ + 2NaCl$$

Regeneration creates this reaction:

$$CaZ + 2NaCl = NaZ + CaCl_2$$

Whenever hard water is run through ion exchangers after the capacity of the volume of ion exchanger is used up, carbonate builds up on the grains of the zeolite. In the case of the organic ion exchangers they can be cleaned with dilute acid, washed free of the acid and then can be used again. In the case of the inorganic ion exchangers, the minerals are destroyed by the action of acids. Any buildup of carbonate reduces the capacity of the inorganic ion exchanger and nothing can be done about it.

Organic cation exchangers may be operated either in the sodium or hydrogen cycle, since they are unaffected by dilute acids used in regeneration for the hydrogen cycle. Reactions of these materials in the sodium cycle are the same as for the inorganic exchangers above. Typical reactions in the hydrogen cycle are:

$$Ca(HCO_3)_2 + 2HR = CaR_2 + 2H_2CO_3$$
$$CaCl_2 + 2HR = CaR_2 + 2HCl$$

Regeneration

$$CaR_2 + H_2SO_4 = 2HR + CaSO_4$$
$$CaR_2 + 2NaCl = 2NaR + 2HCl$$

Through the use of a regenerant consisting of a mixture of a sodium salt and an acid, some of the organic cation exchangers can be used to reduce or eliminate the bicarbonates from raw water, at the same time substituting sodium for calcium and magnesium in sulfates and chlorides present. With this type of regeneration, the exchanger operates in effect, in both hydrogen and sodium cycles:

$$Ca(HCO_3)_2 + HR = CaR + 2H_2CO_3$$
$$CaSO_4 + 2NaR = CaR_2 + Na_2SO_4$$

Regeneration with NaCl and H_2SO_4

$$2CaR_2 + H_2SO_4 + NaCl = 2HR + 2NaR + CaSO_4 + CaCl_2$$

Anion Exchangers

Reactions:

$$RNH + HOH + HCl = RNH_2 + HCl + H_2O$$

The same type of reaction is obtained with sulfuric or nitric acid.

Regeneration with NaOH

$$RNH_2 + HCl + NaOH = RNH_2 + HOH + NaCl$$

Sodium carbonate is used as a source of alkalinity for regeneration of anion exchangers because of the following hydrolysis equilibrium which is established in dilute aqueous solutions:

$$Na_2CO_3 + HOH = NaOH + NaHCO_3$$

When sodium carbonate is used as a regenerant, carbon dioxide is liberated by reaction with carbonate and bicarbonate salts with acid.

By the use of a cation and anion exchanger, degasification of the carbon dioxide formed in the reaction of the anion exchanger, and silica removal by ion exchange, a dionized water can be obtained that is equivalent to, or in some cases even better, than distilled water.

CHEMICALS AND TESTS

Dr. Hall of the Hagan Corporation found that sodium hexametaphosphate could be used in the treatment of boiler feed water to reduce scaling and corrosion in boiler tubes in about 1933. Other chemicals have been developed along this line, the most recent of which is a chemical known as versenate. This is tetrasodium tetraacetic ethylenediamine. It is claimed that this chemical does not break down at high temperatures like the polyphosphates do.

Considerable progress has been made in the use of chlorine in water treatment, particularly in the field of taste and odor removal. The application of large doses of chlorine to the raw water is known as break-point chlorination, and oxidizes the organic matter in the water.

One of the problems that has irked water works men is that of sludge disposal from lime-soda treatment plants. We still have the problem here in Columbus. Estabrook and Hoover both developed systems for obtaining the calcium carbonate in a very pure state and then this can be burned to recover lime to reuse. About a year ago, the Miami Florida plant completed an 80 ton per day capacity lime plant. The magnesium content in their water is low and the lime can be reburned a number of times. They expect to supply all the cities in Florida that use lime in their water works.

A few new methods for testing water have been developed in the period covered. One is an electrical instrument known as the solubridge which is essentially a milliohmmeter arrangement with a photo-electric cell. This instrument is calibrated to read directly in grains per gallon total dissolved solids.

An indicator that was developed in 1941 by Stancil Cooper of Washington University of St. Louis, Missouri, is considerably better than methyl orange in the determination of total alkalinity in water. Many of you may have used this indicator which is a mixture of one gram of brom cresol green and 0.2 gram of methyl red in a liter of isopropyl alcohol.

About the best development in the testing field as far as a water works laboratory is concerned is that of the determination of total hardness by the versenate method. The disodium dihydrogen versonate is used in this case. The solution is standardized against a standard calcium chloride solution just as soap solution is. It only takes a few minutes to run this test and is far superior to the old soap solution method and the soda reagent method for non-carbonate hardness.

I believe that I have covered the important developments in the past 15 years and trust that I have stimulated an interest in you in water, the cheapest commodity on earth, costing the consumer about 6c per ton delivered to his tap.